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EVALUATION OF GPS FOR PRECISE ARTILLERY SURVEY POSITIONING AND POINTING (U)

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA
TECHNICAL NOTE 91-38

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ABSTRACT

Four GPS receivers: the Plessey PA9052, Ashtech XII, Trimble TRIMPACK and Magellan NAV1000M, were evaluated for performance and suitability for the positioning and pointing of artillery.

Specifications for accuracy in positioning and pointing, as defined by STANAG 2373, are 17.5 metres (CEP) and 0.60 mils, respectively.

The receivers were evaluated for static positioning, short and mid-range (≈11km) waypointing (bearing determination), differential positioning and waypointing, kinematic positioning and general receiver characteristics.

The evaluations were carried out in March of 1991 and while Selective Availability (SA) was not implemented.

Static positioning (without SA) met artillery specification. Bearing determination to a given waypoint, both short and mid-range, was 50 to 90 mils but improved under differential GPS processing to better than 2 mils. Kinematic survey yielded indeterminate results.

The use of differential GPS under good satellite geometry conditions and with adequate observation times may be a feasible solution for the artillery survey positioning and pointing requirement.

Other techniques employing GPS which show potential for this application are also discussed.

RÉSUMÉ

Quatre récepteurs GPS, (Plessy PA9052, Ashtech XII, Trimble TRIMPACK et le Magellan NAV1000M), ont été étudiés pour évaluer leur utilité et leur rendement pour le positionnement et le braquage d'artillerie.

Les caractéristiques de précision pour le positionnement et le braquage, d'après le STANAG 2373, sont de 7.5 mètres (CEP et 0.6 mils respectivement).

Les récepteurs furent évalués pour le positionnement statique, le pointage à courte et moyenne distance, le positionnement et le pointage différentiel, le positionnement cinématique et pour leur caractéristiques générales.

Ces évaluations ont été effectuées en mars 1991, sans utiliser l'option de disponibilité sélective (DS).

Le positionnement statique (sans DS) a satisfait les caractéristiques d'artillerie. La détermination du pointage dans une direction donnée à courte et moyenne distance était de 50 à 90 mils, mais s'est amélioré jusqu'à 2 mils en utilisant une technique GPS différentielle. Une étude de positionnement cinématique a donné des résultats indéterminés.

L'emploi de la technique différentielle GPS sous de bonnes conditions de géométrie par satellite et avec des temps d'observation adéquats peut être considéré comme une solution réalisable dans l'étude des spécifications du positionnement et du braquage d'artillerie.

D'autres techniques utilisant le GPS et montrant des possibilités pour cette application sont aussi discutées.

EXECUTIVE SUMMARY

Artillery survey positioning and pointing in the Canadian Forces (CF) is accomplished by the use of a map and hand held compass or by survey techniques employing theodolites. Positioning and pointing accuracies of 50-100 meters and 10-20 mils are typical.

STANAG 2373 'Survey Accuracy Requirements for Surface to Surface Artillery', calls for accuracies of 17.5 meters in position and 0.60 mils in orientation.

The purpose of this evaluation was to investigate the use of the Global Positioning System (GPS) to accomplish the artillery requirements.

Four receivers were evaluated:

a. Plessey PA9052, 5-channel, P-code airborne receiver.

b. Ashtech XII, 12-channel, C/A code receiver.

c. Trimble TRIMPACK, C/A code receiver.

d. Magellan NAV 1000m, single-channel, C/A code receiver.

The receivers were evaluated for static positioning, short and mid-range (≈11 km) waypointing (bearing determination), differential positioning and waypointing, kinematic positioning and general receiver characteristics.

The evaluations were carried out in March of 1991 and while Selective Availability (SA) was not implemented.

Static positioning (without SA) met artillery specification. Bearing determination to a given waypoint, both short and mid-range, was 50 to 90 mils but improved under differential GPS processing to better than 2 mils. Kinematic survey yielded indeterminate results.

The use of differential GPS under good satellite geometry conditions and with adequate observation times may be a feasible solution for the artillery survey positioning and pointing requirement.

Other techniques should be investigated including inertial-based systems such as the Position and Azimuth Determining System (PADS) and a new GPS-based system employing 3 or 4 antennas and using relative phase measurements between antennas to determine attitude.

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1.0 BACKGROUND

1.1 INTRODUCTION

This work was performed under DLAEEM Task 143, 'GPS - Survey Evaluation'. The objective was to assess the capabilities of several Global Positioning (GPS) receivers in both point-positioning and differential modes to meet artillery survey positioning and orientation requirements.

The tasks included:

a. determination of the requirements for precise artillery survey positioning and orientation;

b. development of field test plans to demonstrate the requirements;

c. field testing of available GPS receivers and;

d. provision of a final report detailing the suitability of the tested receivers to meet Army requirements.

The tests were performed between 18 March and 26 March 1991 at DREO. The receivers that were evaluated:

a. Ashtech XII (Course/Acquisition, C/A code)

b. Trimble Trimpac (C/A code)

c. Magellan 1000M (C/A code)

d. Plessey 9052A (Precise, P-code)

Detailed descriptions of each of these receivers are contained later in this report.

A series of first order survey points on the DREO site were used as reference positions.

1.2 ARTILLERY SURVEY POSITIONING AND POINTING REQUIREMENTS

The Canadian military subscribes to the NATO Standardization Agreement (STANAG) No. 2373, 'Survey Accuracy Requirements for Surface to Surface Artillery', dated September 1989.

Under this STANAG, artillery survey accuracy criteria for the 105 mm and 155 mm cannon are stated as:

Orientation	0.60 mils =	(.034°)
Position	17.5 meters	(CEP*)
Altitude	10.0 meters	(PE**)

* CEP (Circular Error Probable) is the radius of the circle, centred about the true position, such that any measured or calculated position has a 50% probability of lying within that circle.

** PE (Probable Error) is a 50% probability of occurrence and applies to both East-West and North-South axes.

Standard procedure employed by the Canadian Forces to position artillery consists of performing a survey using a theodolite and traversing a position from a previously known survey location, perhaps several kilometres away from the desired battery position. Resulting pointing accuracies are of the order of 1 to 3 mils, although, given a reasonably precise survey marker as a reference, a position within several metres is easily possible.

In a practical sense, it is often likely that a reference position would be obtained from a map, giving a grid position to 8 digits at best, or 10 to 20 m, and that a hand compass would be used to obtain bearing to between 5 and 10 mils.

Discussions with CF artillery personnel resulted in agreement that reliable positioning was generally worse than this.

Evidently, this is substantially below the desired accuracy requirement referred to in STANAG 2373.

1.3 GPS AS A POSITIONING AND POINTING SYSTEM

GPS is a highly precise, satellite-based radio navigation and positioning system providing 24-hour global coverage. Although at present all 18 satellites are not yet deployed, coverage by the end of 1991 is expected to be global, 2-dimensional, with full 3-dimensional coverage by 1993.

System performance specifications state GPS positioning accuracies of 16 m for the Precise Positioning Service (PPS) and 100 metres for the Standard Positioning Service (SPS). In practical terms though, a stand-alone user employing C/A code (SPS) can achieve near - PPS accuracies. In response to this, the U.S. Department of Defence has decided to implement Selective Availability

(SA), an intentional degradation of GPS signals by broadcasting of slightly erroneous clock and orbital information. Under SA, SPS accuracy decreases to 100 m (or worse).

During the tests performed under this study, Selective Availability was not implemented. Receiver accuracy, it should be noted, is directly dependant upon satellite geometry with respect to the receiver; usually expressed as PDOP (position dilution of precision). This is particularly important at this time since the full satellite constellation is not yet available and PDOP can vary greatly over time.

A last point to be noted is that GPS provides a position or navigation solution but, in its standard configuration, cannot provide direct attitude information. There is, however, a process by which attitude information can be obtained from GPS and this will be discussed in some detail at the conclusion of this report.

1.4 GPS RECEIVERS

GPS receivers can be designed to operate in various modes depending upon the desired application.

In general, equipment types can be divided into P-Code (PPS) receivers and C/A (SPS) receivers. These receivers can employ one or more RF channels and many forms of signal processing. In the simplest terms, positioning accuracy (under given satellite geometry) of a P-Code receiver in stand-alone static mode is of the order of 16 m while a C/A code receiver can achieve better than 30 m (with no Selective Availability). For certain applications such as surveying, processing techniques have been developed whereby C/A code receivers can be used to achieve sub-meter accuracies. In particular, differential-GPS (DGPS) has become very popular. This technique involves the use of two GPS receivers, one located at a precisely known (reference) location and the other at the point of the (unknown) desired survey. The difference between the receiver position solution at the reference location and the actual position is attributed to system errors and is used as a 'correction' for the unknown location. In actual fact, the correction is obtained from the pseudo-range measurements at each receiver rather than just the position solution. Accuracies of a few centimetres are possible under good conditions if adequate data is collected and processed.

Another technique is that of the 'kinematic' survey, a process by which differential GPS can be used under certain

conditions, in conjunction with carrier phase tracking, to obtain precise positions with very little data collection. (The detailed procedure is described in the test plans).

For this evaluation, both P-Code and C/A code GPS receivers were employed in modes including stand-alone point positioning, differential point-positioning and kinematic survey.

The techniques and processing details are described in the test descriptions and results.

2.0 TEST PLAN

2.1 RATIONALE

The following parameters were defined as a requirement for determining receiver suitability for the artillery survey and positioning problem:

a. Position accuracy; 2D/3D, stand-alone, differential, kinematic

b. Velocity accuracy

c. Waypoint navigation; range and bearing to waypoint, accuracy

d. Receiver processing software; ease of use, performance

e. Post processing software; ease of use, performance

f. Other parameters; effects of foliage attenuation and antenna shielding, effects of dynamics, temperature effects, jamming, etc.

Based upon these general areas, a test plan was developed.

2.2 TEST PLAN DESCRIPTION

The test plan consisted of five sets of tests; static positioning, short range waypointing and mid range waypointing, differential positioning and waypointing, kinematic positioning and general receiver characteristics. The test procedures are now described in detail.

2.2.1 GPS Static Testing

The Ashtech XII, Plessey PA9052, Trimble Trimpack and Magellan 1000M GPS receivers were installed in a truck mounted test bed as shown in Figures 2-1 and 2-2. The Ashtech XII and Magellan 1000M antennae were positioned over a 1st order survey point on the DREO site. The Trimpack receiver was coupled to the Magellan antenna with a Magellan antenna coupler. The Plessey antenna was mounted on the roof of the test bed (test bed positioned 5 meters from the survey point).

The Ashtech antenna was mounted on a tribrack/tripod assembly and positioned (centred and levelled) over the point as shown in Figure 2-3. The Magellan antenna was mounted on a wooden stick and positioned over the same point through one leg of the Ashtech tripod. Another Ashtech XII

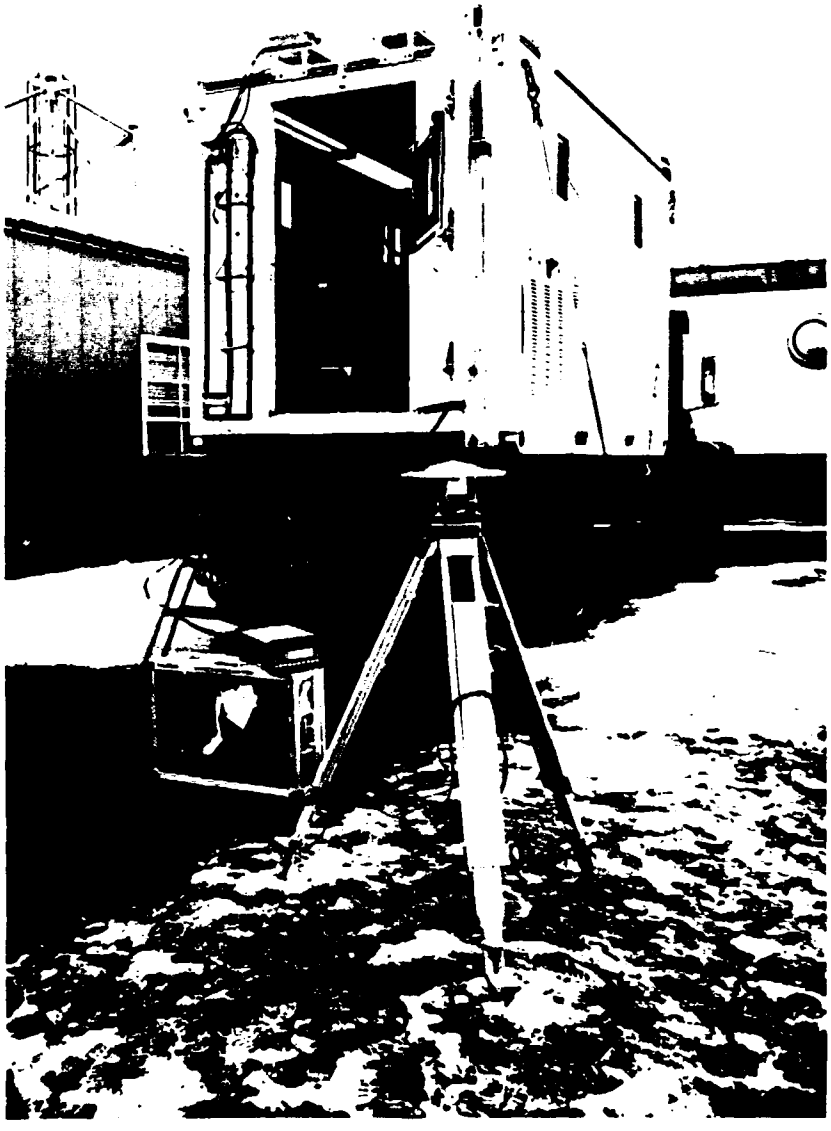

FIGURE 2-1: VAN TEST BED

FIGURE 2-2: INTERIOR OF VAN TEST BED

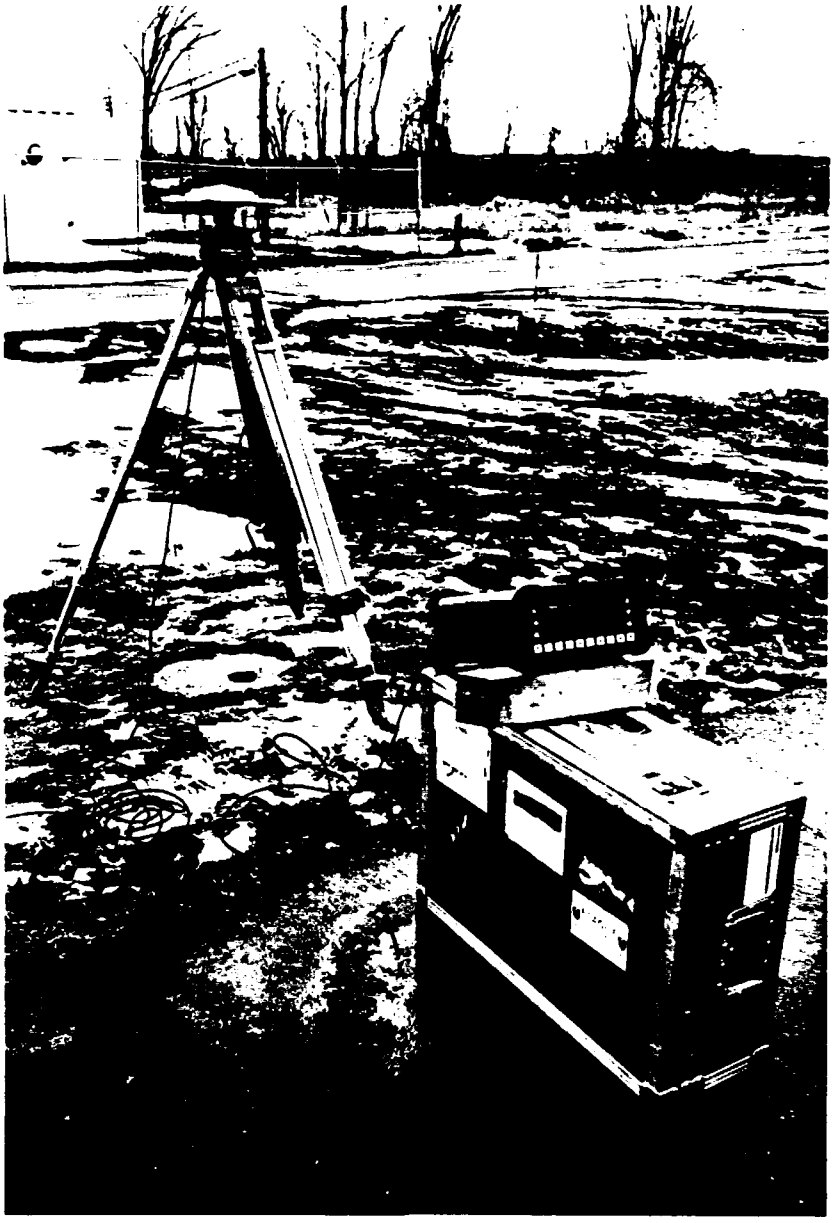

FIGURE 2-3: ASHTECH XII RECEIVER SET-UP

receiver was set up at a nearby 1st order survey point, it's antenna, tribrack/tripod assembly positioned (centred and levelled) over the point.

All receivers were turned on and initialized. Position data was hand recorded for all the receivers in the test bed.

Both Ashtech XII receivers were initialized to record data at 20 sec. intervals during static testing. The data collected was post processed to obtain:

a. static point position

b. differential point position

c. differential range and bearing to a waypoint.

2.2.2 Waypoint Test (Short Range)

The truck mounted test bed (Plessey antenna mounted on the roof) was positioned 5 meters from a 1st order survey point on the DREO site. The Ashtech XII antenna and tribrack/tripod assembly was positioned (centred and levelled) over the point. The Magellan antenna was mounted on a wooden stick and positioned over the same point through a leg of the Ashtech tripod.

All receivers (Ashtech XII, Plessey PA9052, Trimble Trimpack and Magellan 1000M) were turned on and initialized. When 4 or more satellites were acquired, latitudes and longitudes of six 1st order survey points on the DREO site (<1 km away) were entered as waypoints in each of the receivers. Using the initial 1st order point as the reference point, the range and bearing to each of the waypoints was hand recorded for a period of several hours.

2.2.3 Waypoint Test (Midrange)

The truck mounted test bed (Plessey antenna mounted on the roof) was positioned 5 meters from a 1st order survey point on the DREO site. The Ashtech XII antenna and tribrack/tripod assembly was positioned (centred and levelled) over the point. The Magellan antenna was mounted on a wooden stick and positioned over the same point through a leg of the Ashtech tripod.

All receivers were turned on and initialized. When 4 or more satellites were acquired, latitude and longitude of a 1st first order survey point ≈11 km off the DREO site was entered as a waypoint in each of the receivers in the test

bed. Using the first point as the reference point, the range and bearing to the second point were hand recorded.

2.2.4 Differential Point Positioning and Waypoint Test

The truck mounted test bed was positioned 5 meters from a 1st order survey point on the DREO site. The Ashtech XII antenna and tribrack/tripod assembly were positioned (centred and levelled) over the point. The receiver was turned on and initialized. When 4 satellites were acquired, the receiver was set up to record at 5 sec. intervals. Another Ashtech XII receiver was setup nearby at another 1st order survey point, it's antenna, tribrack/tripod assembly positioned (centred and levelled) over that point. The receiver was turned on and initialized. When 4 satellites were acquired this receiver was also set up to record data at 5 sec. intervals for a period of 10 minutes. The receiver was then turned off and moved to another 1st order survey point and it's antenna and tribrack/tripod assembly were positioned (centred and levelled) over that point. The receiver was turned on again and initialized. When 4 satellites were acquired, the receiver was set up to record at 5 sec. intervals for a period of 10 minutes.

The data collected was post-processed to obtain:

a. differential point positioning of several points,

b. differential range and bearing from a reference point to several points.

2.2.5 Kinematic Positioning

The kinematic mode refers to when one receiver is placed at one known point while a second (rover) receiver is placed at a second known point. After a short observation of several minutes, the roving receiver can be moved to additional points where one or two minutes of observation are made. The roving receiver will provide centimeter accuracy for all points as long as four or more satellites with a good PDOP are continuously tracked (no cycle slips).

The truck mounted test bed was positioned 5 meters from a 1st order survey point on the DREO site. The Ashtech XII antenna and tribrack/tripod assembly positioned (centred and levelled) over the point. The receiver was turned on and initialized. When 4 satellites were acquired, the receiver was set up to record at 10 sec. intervals. Another Ashtech XII receiver was setup near another 1st order survey point, it's antenna, tribrack/tripod assembly positioned (centred and levelled) over that point. The receiver, was

turned on and initialized. When 4 satellites were acquired, the receiver was set up to record at 10 sec. intervals for a period of 15 minutes. The receiver while still recording and tracking a minimum of 4 satellites, was moved to another on-site 1st order survey point. The antenna and tribrack/tripod assembly were hand held with one leg of the tripod on that point. Data was recorded for a 5 minute period. Following the same procedure the receiver was moved to another on-site 1st order survey point and the procedure repeated.

The data collected was post processed to obtain kinematic point position.

2.2.6 General Receiver Characteristics

In addition to positioning and waypointing performance tests, each of the receivers was evaluated for general performance including acquisition time, time-to-first-fix (TTFF) and ease of operation. In the case of the Ashtech receivers, the Ashtech GPS Post-Processing System (GPPS) software was also evaluated for ease of use and 'operator-friendliness' since all processing was performed off-line.

2.2.7 Temperature, Anti-Jamming and Foliage Attenuation Tests

These tests were not performed on the evaluated receivers for several reasons. Temperature testing was intended to evaluate receiver performance at low temperatures (nominally -60°C). Since only two of the receivers were mil spec, these tests could have damaged the other receivers. In addition, the P-Code receiver, although mil spec, employed a standard laptop PC as the Control and Display Unit for test purposes. The PC would not withstand the cold temperatures. Temperature specifications were taken from the manufacturer's specifications for all receivers.

Anti-jamming tests could not be performed since there is no facility to perform such tests at DREO.

Foliage attenuation tests were impractical since the tests were performed in March before adequate foliage cover.

3.0 GPS RECEIVER DESCRIPTIONS

3.1 RECEIVER TYPES

The following receivers were employed during the tests:

a. Ashtech XII, C/A code, 12 channel

b. Magellan NAV 1000M, C/A code, single channel

c. Trimble TRIMPACK, C/A code, 2-channel

d. Plessey PA 9052A, P-code, 5-channel

e.* Canadian Marconi CMC 772, P-code, 2 channel

* The CMC receiver is of a very primitive design and, for unknown reasons, was unable to acquire and track more than two satellites. After numerous attempts, evaluation of this receiver was abandoned. No data on the CMC receiver is contained in the results of this report.

Specifications for the evaluated receivers are contained in the following sections.

3.1.1 Ashtech XII

The Ashtech XII is an automatic, 12-channel receiver which will track all satellites in view at all times. It requires no calibration or initialization and contains built-in RAM data storage capability. The receiver is designed to operate in either stand-alone or differential mode, either realtime or post-processed through Ashtech-provided software. Kinematic surveying can also be performed and results obtained through a special software package.

Receiver specifications are contained in Table 3-1.

Present cost is $25 - $40 K, depending on options.

RESOLUTION & ACCURACY

Measured and Computed Data

Carrier Phase	0.1 mm rms
Code phase	1 meter
Code phase Smoothed	few centimeters
Doppler	0.001 Hz
Integrated Doppler	3 mm
Position	20 m (depends on broadcast orbit) GDOP < 6
Real-time Differential Position	1 m
Velocity	1 cm/sec (0.02 Knot) GDOP < 6

Environmental:

Temperature Range	
Receiver/data logger	
operating	-20 to +55 degree C
storage	-30 to +75 degree C
Antenna	
operating	-40 to +65 degree C
storage	-55 to +75 degree C
Humidity	100 %
Weight of Receiver	10 pounds
Weight of Antenna	
Precision Antenna Platform	2.5 pounds
Tripod mountable/detachable	1.5 pounds

Standard Features:

12 Channel "All-in-View Operation"
16 Watt Power Consumption
9 to 32 volts input voltage range
2 Isolated power inputs
Audible alarm for low power
Internal RAM Data recording
14 hours of recording
8-lines by 40-character display
38,400 RS232 baud (max)
2 RF stages
Static, Kinematic, Psuedo Kinematic Surveys
2 minute cold start to first data
Automatic post processing software
No need for power-on calibration
No need for initial estimate of position
No need for operation mode selection
No need for warm-up time

TABLE 3-1 Ashtech XII GPS Receiver Specifications*

*Provided by Manufacturer

3.1.2 Magellan NAV 1000M

The Magellan NAV 1000M receiver is a single channel, fast-sequencing C/A code receiver. It was designed to be a hand-held unit employing simple-to-use features.

Specifications for the receiver are given in Table 3-2.

This receiver is typically employed by ground forces either on foot or in vehicles.

Present cost is approximately $3K.

SPECIFICATIONS

Physical Characteristics	
Unit Size:	21.5 cm x 9.0 cm x 5.0 cm excluding antenna;
Weight:	0.85 kg with batteries
Display:	4 line, 16 character, alphanumeric, backlighted LCD
LCD Dimension:	6.5 cm x 4.5 cm; 0.70 cm high digits (with cursor)
Operating:	-10 C to 60 C (typical)
Waterproof:	Unit waterproof; battery compartment water resistant
Buoyancy:	Specific gravity = 0.8 (it floats)
Safe Storage Temperature:	-40 to 70 C
GPS Exterior Antenna:	9.0 cm x 9.0 cm, 15 meters of cable (See Instructions for the GPS Exterior Antenna Kit)
Data Characteristics	
Accuracy:	(HDOP<2, $C/N_0 \geq 47$ dB-Hz, 2D) POS - 25 meter RMS in 2D*, 30 meter RMS 3D (horizontal) VELOCITY -0.3 Knots RMS
Speed:	0 to 320 Km/h (200 MPH)
Time to First Fix:	2.5 minutes (2D) typical; 3.0 minutes (3D) typical
Time to Subsequent Fix:	15 seconds (2D) typical 20 seconds (3D) typical
Almanac Collect:	12.5 minutes typical
Memory:	50 user-stored waypoints plus 5 last fixes.
Electrical Characteristics	
Receiver:	Fast single channel
Power Requirements:	6 AA alkaline batteries (internal) or 12 (10 to 15) volts DC with adapter
Power Consumption:	260 MA typical without light (9 volts) 310 MA typical with light (9 volts)
Battery Life:	Up to 7 hours continuous typical; 75+ single fixes (push-to-fix) typical
Modes of Operation:	2D (solves for LAT, LON and time with a user-entered altitude using best 3 satellites) or 3D (solves for LAT, LON altitude, and time using best 4 satellites)

TABLE 3-2 Magellan NAV 1000M Receiver Specifications*

* Provided by Manufacturer

3.1.3 Trimble TRIMPACK

The Trimble TRIMPACK receiver is a low to moderate dynamics unit designed to meet most military environmental specifications. It is used in a stand-alone navigation mode.

Receiver specifications are shown in Table 3-3.

Receiver cost is ≈$7K.

Performance	
Autonomous position	- 25 meters SEP
Velocity	- 0.2 meters/second, RMS steady state
Time	- Universal Coordinated Time to the nearest microsecond
Dynamics	- Velocity 0-600 knots - Acceleration 2g (tracking)
Power	
Internal Batters	- Two cell configuration (standard) operates with two lithium D cells. - Four cell configuration (optional) operates with nicad, lithium or alkaline D cells
Source Life With Batteries	- 18-20 hours continuous with 2 lithium D cells - 35-45 ;hours continuous with 4 lithium D cells - 50-60 hours intermittent (4 fixes/hour) with 2 lithium cells) - 100-200 hours intermittent (4 fixes/hour) with 4 lithium D cells
External Power Input	- Accepts 5 to 32 VDC from a 5 Watt power source - Power cable is terminated in a NATO connector on the vehicle end
Physical Characteristics	
Weight	- 2 cell configuration: 1.5 kg (3.3 lbs.) - 4 cell configuration: 1.9 kg (4.2 lbs.)
Size	- Approximately 16.5X17.8X4.9 cm (6.5X7.0X2 in) - Volume 1491 cm^3 91 cu in)
Environmental (Tested to MIL-STD-810D)	
Temperature	- -30 to +65 degrees C
Temperature, Non-operating	- -55 to +85 degrees C
Shock	- Operating: 15g for 11 milliseconds
Vibration	- Operating: 4g RMS, 20 to 1200 Hz Endurance: 8g RMS, 100 to 1200 Hz
Immersion	- 2 meters in water
Humidity	- 100% condensing
Salt Fog	- 200 hours with no corrosion
Sand and Dust	- Sandproof and dustproof
Altitude	- -400 to +15,000 meters
Icing (remote antenna)	- Ice does not cause physical damage
EMI/EMC	- Per MIL-STD-461/Tested per MIL-STD-462 for Army Vehicle environment

TABLE 3-3 TRIMPACK Receiver Specifications*

*Provided by Manufacturer

3.1.4 Plessey PA9052

The Plessey PA9052 receiver is a 5-channel, high dynamics, airborne, P-code receiver built to full military specifications. The receiver calculates ionospheric correction through the use of both L1 and L2 frequencies. The receiver employed for these tests used a laptop PC as a Control and Display Unit (CDU) which also permitted additional recording and data analysis capabilities through Plessey engineering and development software.

Receiver Specifications are contained in Table 3-4.

Receiver cost is $80K-$100K.

SPECIFICATIONS

Performance

Position accuracy (2D)	18 metres 95% (Navstar System Limit)
Velocity accuracy	0.5 metres/second rms (10Hz) 0.2 metres/second rms (1 second average)
Velocity range	0-1200 metres/second
Time Mark Accuracy	500 nanoseconds 95%

Physical

Dimensions	90mm x 194mm x 319mm (3/8 ATR short)
Weight	5kg (Receiver) 0.5kg (Mounting Tray)

Power

Primary	115V 400Hz 50 Watts
Back up	6V to 40V at 20μA max (Protected to 80V surge, 600V spike)
Temperature	-54°C to +70°C (Operating) -62°C to +85°C (Non-operating)
Altitude	70,000 feet at 60°C maximum
MTBF	2,250 hours at 50°C case (AUF)

TABLE 3-4 Plessey PA9052 Receiver Specifications*

*Provided by Manufacturer

4.0 TEST RESULTS

4.1 REFERENCE POSITIONS

The reference positions used as waypoints during the tests were selected from a list of survey points resulting from a survey performed by the Mapping and Charting Establishment (MCE) in 1987. The control survey points are accurate to ≈ 1 cm.

The list of survey points used is contained in Table 4-1.

FINAL ADJUSTED PRIMARY CONTROL

WGS 72

STA NUMBER	STA NAME	LAT	LONG	ELEV(M)
8635001	P1	45 21' 18.306"	75 53' 00.964"	64.748
8635003	P3	45 21' 28.088"	75 53' 06.951"	64.260
8635004	P4	45 21' 31.599"	75 53' 03.413"	64.134
8635005	P5	45 21' 32.618"	75 52' 56.833"	64.026
8635006	P6	45 21' 29.129	75 52' 51.997"	64.528
8635007	P7	45 21' 24.379"	75 52' 49.561"	64.889
8635009	P9	45 21' 17.951	75 52' 54.109"	64.830
8635012	P12	45 20' 57.801"	75 53' 26.820"	79.826
8635017	P17	45 20' 55.598"	75 53' 04.567"	74.052
8635018	P18	45 20' 54.631"	75 53' 09.686"	73.721
653001		45 22' 20.505"	75 44' 36.880'	114.066

TABLE 4-1 DREO Control Survey Points

4.2 GPS STATIC TEST RESULTS

On the 19th of March 1991, static point positioning was performed with the Ashtech XII GPS receiver. Following the procedures outlined previously, measurements were taken at 1st order survey point 8635018. The Ashtech XII receiver data was recorded at 20 second intervals from 14:33 to 17:25 GMT. Hand recorded measurements were taken at 5 minute intervals for a period of 50 minutes during 5 satellite coverage (table 4-2) and 35 minutes during 3 satellite coverage (table 4-3). During 5 satellite coverage, the mean delta latitude in meters between the actual point position and GPS measured position was 10.587 m with a

standard deviation of 1.632 m. The mean delta longitude in meters between the actual point position and the GPS measured position was 10.087 m with a standard deviation of 3.591 m. During 3 satellite coverage, the mean delta latitude in meters between the actual point position and GPS measured position was 8.736 m with standard deviation of 1.980 m. The mean delta longitude in meters between the actual point position and the GPS measured position was 5.054 m with a standard deviation of 0.544 m. Note that the increased accuracy estimate under 3 satellite coverage is due to the improved PDOP as compared to 5 satellite coverage.

A second Ashtech XII receiver recorded data at 1st order survey point 8635017 at 20 second intervals from 14:34 to 17:27 GMT. The data recorded by both receivers was post processed by the Ashtech XII GPS Post-Processing System software.

DATE: 19/03/1991

SURVEY POINT: 8635018

LATITUDE: 45 20'54.631" 45 20.9151'

LONGITUDE: 75 53'09.686" 75 53.1614'

GMT TIME	MEASURED LATITUDE	MEASURED LONGITUDE	NO.SATELLITES/ PDOP
15:40	45 20.9158'	75 53.1512'	5/2
15:45	45 20.9163'	75 53.1484'	5/2
15:50	45 20.9172'	75 53.1507'	5/2
15:55	45 20.9150'	75 53.1568'	5/2
16:00	45 20.9168'	75 53.1549'	5/2
16:05	45 20.9175'	75 53.1536'	5/2
16:10	45 20.9159'	75 53.1564'	5/2
16:15	45 20.9167'	75 53.1526'	5/2
16:20	45 20.9155'	75 53.1526'	5/2
16:25	45 20.9171'	75 53.1556'	5/2
16:30	45 20.9147'	75 53.1577'	5/2

MEAN LATITUDE: 45 20.91623 45 20'54.9738"

MEAN LONGITUDE: 75 53.15368 75 53'09.2208"

DELTA LATITUDE: 45 20'54.974" (MEASURED)
45 20'54.631" (8635018)
0.343" 1 sec. LAT.= 30.867 m.

DELTA LATITUDE: 0.343 sec. X 30.867 m./sec.= 10.587 m, 1.63 m 2σ

DELTA LONGITUDE: 75 53'09.221" (MEASURED)
75 53'09.686" (8635018)
0.465" 1 sec. LONG.= 21.693 m.

DELTA LONGITUDE: 0.465 sec. X 21.693 m./sec.= 10.087 m, 3.59 m 2σ

TABLE 4-2 ASHTECH GPS RECEIVER STATIC TEST

DATE: 19/03/1991

SURVEY POINT: 8635018

LATITUDE: 45 20'54.631" 45 20.9151'

LONGITUDE: 75 53'09.686" 75 53.1614'

GMT TIME	MEASURED LATITUDE	MEASURED LONGITUDE	NO.SATELLITES/ PDOP
16:40	45 20.9165'	75 53.1567'	3/1
16:45	45 20.9171'	75 53.1574'	3/1
16:50	45 20.9149'	75 53.1575'	3/1
16:55	45 20.9152'	75 53.1574'	3/1
17:00	45 20.9157'	75 53.1576'	3/1
17:05	45 20.9143'	75 53.1582'	3/1
17:10	45 20.9142'	75 53.1580'	3/1
17:15	45 20.9139'	75 53.1576'	3/1

MEAN LATITUDE: 45 20.91523 45 20'54.9138"

MEAN LONGITUDE: 75 53.15755 75 53'09.4530"

DELTA LATITUDE: 45 20'54.914" (MEASURED)
45 20'54.631" (8635018)
0.283" 1 sec. LAT.= 30.867 m.

DELTA LATITUDE: 0.283 sec. X 30.867 m./sec.= 8.736 m, 1.98 m 2σ

DELTA LONGITUDE: 75 53'09.453" (MEASURED)
75 53'09.686" (8635018)
0.233" 1 sec. LONG.= 21.693 m.

DELTA LONGITUDE: 0.233 sec. X 21.693 m./sec.= 5.054 m, 0.54 m 2σ

TABLE 4-3 ASHTECH GPS RECEIVER STATIC TEST

The post processed point solution (table 4-4) for point 8635018 shows latitude and longitude with a software-estimated accuracy of 8 m. The calculated delta latitude in meters between the actual point position and GPS measured position was 14.415 m. The delta longitude in meters between the actual point position and GPS-measured position was 12.734 m.

The post processed point solution (table 4-5) for point 8635017 shows latitude and longitude with a software estimated accuracy of 8 m. The calculated delta latitude in meters between the actual point position and the GPS-measured position was 15.063 m. The calculated delta longitude in meters between the actual point position and the GPS measured position was 12.452 m.

The Ashtech GPS Post-Processing Software provides an estimate of accuracy,the criteria for which is not clearly defined but is comparable to our calculated accuracies.

DATE: 19/03/1991

SURVEY POINT: 8635018

LATITUDE: 45 20'54.631" 45 20.9151'

LONGITUDE: 75 53'09.686" 75 53.1614'

Ashtech XII GPS receiver serial no. 225
antenna serial no. 184

The receiver antenna was mounted on a tribrack/tripod assembly and positioned (levelled and centred) over first order survey point 8635018.

Record interval 20 sec.
Data collection was started at 14:33 GMT
Data collection was stopped at 17:25 GMT

A point position solution was calculated by the ASHTECH GPS Post Processing Software using data collected by the receiver.

POST PROCESSING POINT SOLUTION: **LATITUDE:** 45 20'55.0985"

LONGITUDE: 75 53'09.0990"

DELTA LATITUDE: 45 20'55.098" (MEASURED)
45 20'54.631" (8635018)
0.467" 1 sec. LAT.= 30.867 m.

DELTA LATITUDE: 0.467 sec. X 30.867 m./sec.= 14.415 m.

DELTA LONGITUDE: 75 53'09.099" (MEASURED)
75 53'09.686" (8635018)
0.587" 1 sec. LONG.= 21.693 m.

DELTA LONGITUDE: 0.587 sec. X 21.693 m./sec.= 12.734 m.

TABLE 4-4 ASHTECH GPS RECEIVER STATIC TEST

DATE: 19/03/1991

SURVEY POINT: 8635017

LATITUDE: 45 20'55.598" 45 20.9266

LONGITUDE: 75 53'04.567" 75 53.0761

Ashtech XII GPS receiver serial no. 295
antenna serial no. 010

The receiver antenna was mounted on a tribrack/tripod assembly and positioned (levelled and centred) over first order survey point 8635017.

Record interval 20 sec.
Data collection started at 14:35 GMT
Data collection stopped at 17:27 GMT

A point position solution was calculated by the ASHTECH GPS Post Processing Software using data collected by the receiver.

POST PROCESSING POINT SOLUTION: **LATITUDE:** 45 20'56.0856"

LONGITUDE: 75 53'03.9931"

DELTA LATITUDE: 45 20'56.086" (MEASURED)
45 20'55.598" (8635017)
0.488" 1 sec. LAT.= 30.867 m.

DELTA LATITUDE: 0.488 sec. X 30.867 m./sec.= 15.063 m.

DELTA LONGITUDE: 75 53'03.993" (MEASURED)
75 53'04.567" (8635017)
0.574" 1 sec. LONG.= 21.693 m.

DELTA LONGITUDE: 0.574 sec X 21.693 m./sec.= 12.452 m.

TABLE 4-5 ASHTECH GPS RECEIVER STATIC TEST

On the 20th of March 1991, another static point positioning test was performed. Measurements were taken at 1st order survey point 8635018. The Ashtech XII receiver recorded data at 10 sec. intervals from 14:05 to 17:08 GMT. Hand recorded measurements were also taken at 5 minute intervals for a period of 45 minutes during 4 satellite coverage (table 4-6) and at 2 minutes intervals for a period of 21 minutes during 3 satellite coverage (table 4-7). During the 4 satellite coverage, the mean delta latitude in meters between the actual point position and the GPS measured position was 0.123 m with a standard deviation of 6.032 m. The mean delta longitude in meters between the actual point position and the GPS measured position was 3.861 m with a standard deviation of 2.392 m. During 3 satellite coverage, the mean delta latitude in meters between the actual point position and the GPS measured position was 38.337 m with a standard deviation of 8.923 m. The mean delta longitude in meters between the actual point position and the GPS measured position is 9.860 m with a standard deviation of 2.201 m. During 5 to 4 satellite coverage the Plessey receiver data was hand recorded at 5 minute intervals for a period of 55 minutes (table 4-8). The delta latitude in meters between the actual point and the GPS measured position was 1.512 m with a standard deviation of 4.43 m. The mean longitude in meters between the actual point position and the GPS measured position was 2.386 m with a standard deviation of 6.16 m. During 5 to 3 satellite coverage, the Trimpack receiver data was hand recorded at 5 minute intervals for a period of 55 minutes (table 4-9). The mean delta latitude between the actual position and the GPS measured position was 4.198 m with a standard deviation of 5.68 m. The mean delta longitude between the actual point position and the GPS measured position was 24.882 m with a standard deviation of 5.11 m. Because of 'finger play' problems with the Magellan 1000M, only 2 readings were taken during 3 satellite coverage. The mean delta latitude in meters between the actual point position and the GPS measured position was 16.67 m. The mean delta longitude in meters between the actual point position and the GPS measured position was 130.16 m. This data cannot be considered reliable.

DATE: 20/03/1991

SURVEY POINT: 8635018 **ELEVATION:** 73.721 m.

LATITUDE: 45 20'54.631" 45 20.9151'

LONGITUDE: 75 53'09.686" 75 53.1614'

GMT TIME	MEASURED LATITUDE	MEASURED LONGITUDE	ELEV. METERS	NO.SATELLITES/ PDOP
14:25	45 20.9120'	75 53.1607'	76.03	4/5
14:30	45 20.9110'	75 53.1617'	75.58	4/5
14:35	45 20.9096'	75 53.1600'	74.91	4/5
14:40	45 20.9011	75 53.1595'	77.00	4/4
14:46	45 20.9120'	75 53.1582'	78.69	4/3
14:50	45 20.9126'	75 53.1566'	76.00	4/3
14:55	45 20.9115'	75 53.1569'	78.55	4/3
15:00	45 20.9120'	75 53.1557'	79.69	3/2
15:05	45 20.9122'	75 53.1579'	72.99	4/5
15:10	45 20.9118'	75 53.1575'	58.88	4/5

MEAN LATITUDE: 45 20.91058 45 20'54.6348" **MEAN ELEVATION:** 74.832m.

MEAN LONGITUDE: 75 53.15847 75 53'09.5082"

DELTA LATITUDE: 45 20'54.635" (MEASURED)
45 20'54.631" (8635018)
0.004" 1 sec. LAT.= 30.867 m.

DELTA LATITUDE: 0.004 sec. X 30.867 m./sec.= 0.123 m, 6.03 m 2σ

DELTA LONGITUDE: 75 53'09.508" (MEASURED)
75 53'09.686" (8635018)
0.178" 1 sec. LONG.= 21.693 m.

DELTA LONGITUDE: 0.178 sec. X 21.693 m./sec.= 3.861 m, 2.39 m 2σ

DELTA ELEVATION: 74.832 m.(MEASURED) - 73.721 m.(8635018)= 1.111 m.

TABLE 4-6 ASHTECH GPS RECEIVER STATIC TEST

DATE: 20/03/1991

SURVEY POINT: 8635018 **ELEVATION:** 73.721 m.

LATITUDE: 45 20'54.631" 45 20.9151'

LONGITUDE: 75 53'09.686" 75 53.1614'

GMT TIME	MEASURED LATITUDE	MEASURED LONGITUDE	ELEV. METERS	NO.SATELLITES/ PDOP
16:40	45 20.9371'	75 53.1672'	181	3/1
16:43	45 20.9340'	75 53.1660'	181.5	3/1
16:46	45 20.9339'	75 53.1664'	181.54	3/1
16:48	45 20.9313	75 53.1693'	181.54	3/1
16:50	45 20.9307'	75 53.1696'	181.54	3/1
16:52	45 20.9396'	75 53.1697'	181.54	3/1
16:54	45 20.9290'	75 53.1695'	181.54	3/1
16:56	45 20.9278'	75 53.1710'	181.54	3/1
16:59	45 20.9251'	75 53.1699'	181.54	3/1
17:01	45 20.9236'	75 53.1709'	181.54	3/1

MEAN LATITUDE: 45 20.93121 45 20'55.8726" **MEAN ELEVATION:** 181.482m.

MEAN LONGITUDE: 75 53.16895 75 53'10.1370"

DELTA LATITUDE: 45 20'55.873" (MEASURED)
45 20'54.631" (8635018)
1.242" 1 sec. LAT.= 30.867 m.

DELTA LATITUDE: 1.242 sec. X 30.867 m./sec.= 38.337 m, 8.92 m 2σ

DELTA LONGITUDE: 75 53'10.137" (MEASURED)
75 53'09.686" (8635018)
0.451" 1 sec. LONG.= 21.693 m.

DELTA LONGITUDE: 0.451 sec. X 21.693 m./sec.= 9.860 m, 2.20 m 2σ

DELTA ELEVATION: 181.482 m.(MEASURED)- 73.721 m.(8635018)=107.761m.

TABLE 4-7 ASHTECH GPS RECEIVER STATIC TEST

DATE: 20/03/1991

SURVEY POINT: 8635018 **ELEVATION:** 73.721 m.

LATITUDE: 45 20'54.631" 45 20.9151'

LONGITUDE: 75 53'09.686" 75 53.1614'

GMT TIME	MEASURED LATITUDE	MEASURED LONGITUDE	ELEV. METERS	NO.SATELLITES/ EPE
14:05	45 20.911'	75 53.161'	-	5/<10m.
14:10	45 20.910'	75 53.162'	85	5/<10m.
14:15	45 20.909'	75 53.163'	86	5/<10m.
14:20	45 20.908'	75 53.164'	88	5/<10m.
14:25	45 20.908'	75 53.163'	85	4/<10m.
14:30	45 20.905'	75 53.169'	96	5/≈5m.
14:35	45 20.911'	75 53.159'	81	5/≈5m.
14:40	45 20.912'	75 53.157'	75	5/≈10m.
14:45	45 20.915'	75 53.152'	69	4-5/≈5m.
14:50	45 20.908'	75 53.156'	68	4-5/≈5m.
14:55	45 20.909	75 53.155'	70	4-5/≈5m.
15:00	45 20.910'	75 53.154'	76	5/≈3m.

MEAN LATITUDE: 45 20.9097' 45 20'54.582" **MEAN ELEVATION:** 79.91 m.

MEAN LONGITUDE: 75 53.1596' 75 53'09.576"

DELTA LATITUDE:
45 20'54.582" (MEASURED)
45 20'54.631" (8635018)
0.049" 1 sec. LAT.= 30.867 m.

DELTA LATITUDE: 0.049 sec. X 30.867 m./sec.= 1.512 m, 4.43 m 2σ

DELTA LONGITUDE:
75 53'09.576" (MEASURED)
75 53'09.686" (8635018)
0.110" 1 sec. LONG.= 21.693 m.

DELTA LONGITUDE: 0.110 sec. X 21.693 m./sec.= 2.386 m, 6.16 m 2σ

DELTA ELEVATION: 79.91 m.(MEASURED)- 73.72 m.(8635018)= 6.19 m.

TABLE 4-8 PLESSEY GPS RECEIVER STATIC TEST

DATE: 20/03/1991

SURVEY POINT: 8635018 **ELEVATION:** 73.721 m.

LATITUDE: 45 20'54.631" 45 20.9151'

LONGITUDE: 75 53'09.686" 75 53.1614'

GMT TIME	MEASURED LATITUDE	MEASURED LONGITUDE	ELEV. METERS	NO.SATELLITES
14:05	45 20'54.7"	75 53'11.0"	-	5
14:10	45 20'55.1"	75 53'10.4"	-	5
14:15	45 20'54.7"	75 53'11.3"	-	5
14:20	45 20'54.8"	75 53'10.8"	-	5
14:25	45 20'54.6"	75 53'10.9"	-	4
14:30	45 20'54.4"	75 53'11.0"	-	4
14:35	45 20'54.6"	75 53'10.7"	91	4
14:40	45 20'54.7"	75 53'10.6"	96	4
14:45	45 20'54.9"	75 53'11.0"	98	4
14:50	45 20'55.0"	75 53'10.7"	94	4
14:55	45 20'54.8"	75 53'11.0"	91	3
15:00	45 20'54.9"	75 53'10.6"	101	3

MEAN LATITUDE: 45 20'54.767" **MEAN ELEVATION:** 95.17 m.

MEAN LONGITUDE: 75 53'10.833"

DELTA LATITUDE: 45 20'54.767" (MEASURED)
45 20'54.631" (8635018)
0.136" 1 sec. LAT.= 30.867 m.

DELTA LATITUDE: 0.136 sec. X 30.867 m./sec.= 4.198 m, 5.68 m 2σ

DELTA LONGITUDE: 75 53'10.833" (MEASURED)
75 53'09.686" (8635018)
1.147" 1 sec. LONG.= 21.693 m.

DELTA LONGITUDE: 1.147 sec. X 21.693 m./sec.= 24.882 m, 5.11 m 2σ

DELTA ELEVATION: 95.17 m.(MEASURED)- 73.72 m.(8635018)= 21.45 m.

TABLE 4-9 TRIMPACK GPS RECEIVER STATIC TEST

On the 22nd of March 1991, a third static test was performed for the Ashtech XII GPS receiver. Measurements were taken at 1st order survey point 8635017. Hand recorded measurements were taken at 2 minute intervals for a period of 18 minutes during 4-5 satellite coverage (table 4-10). The mean delta latitude between the actual point position and the GPS measured position was 11.112 m. with a standard deviation of 2.874 m. The mean delta longitude between the actual point position and the GPS measured position was 11.844 m. with a standard deviation of 4.343 m.

Table 4-11 is a summary of the static point-positioning results from all of the receivers. All receivers achieved the positioning accuracy expected with variations due mainly to differences in the satellite geometry (PDOP).

DATE: 22/03/1991

SURVEY POINT: 8635017

LATITUDE: 45 20'55.598" 45 20.9266'

LONGITUDE: 75 53'04.567" 75 53.0761'

GMT TIME	MEASURED LATITUDE	MEASURED LONGITUDE	NO.SATELLITES/ PDOP
15:22	45 20.9336'	75 53.0590'	4/2
15:24	45 20.9323'	75 53.0684'	4/2
15:26	45 20.9342'	75 53.0652'	5/2
15:28	45 20.9326'	75 53.0668'	5/2
15:30	45 20.9331'	75 53.0684'	5/2
15:32	45 20.9319'	75 53.0677'	5/2
15:34	45 20.9356'	75 53.0642'	5/2
15:36	45 20.9301'	75 53.0705'	5/2
15:38	45 20.9305'	75 53.0710'	5/2
15:40	45 20.9324'	75 53.0689'	5/2

MEAN LATITUDE: 45 20.93263 45 20'55.9578"

MEAN LONGITUDE: 75 53.06701 75 53'04.0206"

DELTA LATITUDE: 45 20'55.958" (MEASURED)
45 20'55.598" (8635017)
0.360" 1 sec. LAT.= 30.867 m.

DELTA LATITUDE: 0.360 sec. X 30.867 m./sec.= 11.112 m, 2.87 m 2σ

DELTA LONGITUDE: 75 53'04.021" (MEASURED)
75 53'04.567" (8635017)
0.546" 1 sec. LONG.= 21.693 m.

DELTA LONGITUDE: 0.546 sec. X 21.693 m./sec.= 11.844 m, 4.34 m 2σ

TABLE 4-10 ASHTECH GPS RECEIVER STATIC TEST

* GPS Post Processing Software point position solution

** Ashtech GPS post Processing Software estimate of accuracy

*** Plessey EPE (estimated position error)

NOTE: Delta latitude and delta longitude are the differences in latitude and longitude between a 1st order survey point position and the GPS measured position, in meters.

RECEIVER	NO.SAT/ PDOP	DELTA LAT. METERS	STD. DEV. METERS	DELTA LONG. METERS	STD. DEV. METERS
ASHTECH	5/2	10.587	1.632	10.087	3.591
ASHTECH	3/1	8.736	1.980	5.054	0.544
ASHTECH	5/2-3/1	14.415*	8.0**	12.734*	8.0**
ASHTECH	5/2-3/1	15.063*	8.0**	12.452*	8.0**
ASHTECH	4/5	0.123	6.032	3.861	2.392
ASHTECH	3/1	38.337	8.923	9.860	2.201
ASHTECH	4-5/2	11.112	2.874	11.844	4.343
PLESSEY	5-4/***	1.512	4.43	2.386	6.16
TRIMPACK	5-3	4.198	5.68	24.882	5.11

TABLE 4-11 GPS STATIC POINT POSITIONING SUMMARY

4.3 WAYPOINT TEST RESULTS; SHORT AND MID RANGE

On the 20th of March 1991, a waypoint test (short range) was performed with the Ashtech XII, Plessey PA9052A, Trimble Trimpack and Magellan 1000M receivers. Following the procedures outlined previously, measurements were taken from a reference position (1st order survey point 8635018) to a selected waypoint (1st order survey point 8635017). The Ashtech receiver measurements were recorded for a period of 26 minutes (table 4-12) during 5 satellite coverage. The mean delta range from the reference point to the waypoint was 5.987 m with standard deviation of 1.90 m. The mean delta bearing was 1.045° with standard deviation of 0.46°. The Ashtech measurements were also recorded for a period of 19 minutes (table 4-13) during 3 satellite coverage. The mean delta range from the reference point to the waypoint was 7.013 m with standard deviation 1.83 m. The mean delta bearing was 18.145° with standard deviation 2.99°. The Plessey receiver measurements were hand recorded for a period of 53 minutes (table 4-14). The mean delta range from the reference point to the waypoint was 1.38 m with standard deviation of 6.83 m. The mean delta bearing was 1.36° with standard deviation of 1.51°. The Trimpack

receiver measurements were hand recorded for a period of 53 minutes (table 4-15). The mean delta range from the reference point to the waypoint was 24.0 m with standard deviation of 6.11 m. The mean delta bearing was 4.2° with standard deviation of 3.10°. Because of 'finger play' problems with the Magellan, no data was recorded during this test.

On the 21st of March 1991, another waypoint test (short range/6 waypoints) was performed with all of the receivers. Measurements were taken from the reference position (1st order survey point 8635001) to 6 waypoints (1st order survey points 8635003, 8635004, 8635005, 8635006, 8635007 and 8635009). For the Ashtech receiver, a series of 7 measurements were taken for each of the waypoints, while for the Plessey and the Trimpack receivers, a series of 3 measurements were taken for each of the six waypoints. For the Magellan 3 readings were taken for one waypoint only. For the Ashtech receiver the mean delta range from the reference point to the 6 waypoints was 12.07 m with standard deviation of 5.14 m (table 4-16). The mean delta bearing to the 6 waypoints was 3.97° with standard deviation of 1.76°. For the Plessey receiver the mean delta range from the reference point to the 6 waypoints was 12.11 m with standard deviation of 7.73 m (table 4-17). The mean delta bearing to the 6 waypoints was 4.04° with standard deviation of 1.72°. For the Trimpack, the mean delta range from the reference point to the 6 waypoints was 12.03 m with standard deviation of 6.03 m (table 4-18). The delta mean bearing to the 6 waypoints was 4.06° with standard deviation of 2.75°. For the Magellan the mean delta range from the reference point to the waypoint was 35.36 m with standard deviation of 4.71 m (table 4-19). The mean delta bearing was 14.27° with standard deviation of 2.83°.

On the 22nd of March 1991, a third waypoint test (midrange/1 waypoint) was performed with all of the receivers. Following the procedures outlined, measurements were taken from the reference position (1st order survey point 8635017), to a waypoint off site (1st order survey point 653001) a distance of 11 km away. The Ashtech data (table 4-20) was recorded for a period of 18 minutes. The mean delta range from the reference to the waypoint was 54 m with standard deviation of 2 m. The mean delta bearing was 0.086°. The Plessey data (table 4-21) was recorded for a period of 30 minutes. The mean delta range from the reference point to the waypoint was 21 m with standard deviation of 23 m. The mean delta bearing was 0.066° with standard deviation of 0.13°. The Trimpack data (table 4-22) was recorded for a period of 30 minutes. The mean delta range from the reference point to the waypoint was 79 m. The mean delta bearing was 0.316°.

In summary, as could be expected, waypoint distance and bearing accuracy improve with the distance between the waypoints. At the 'midrange' distance, 11 km, both the Ashtech and Plessey receivers give a bearing to better than 0.1° (<2 mil) in a stand-alone mode.

DATE: 20/03/1991

SURVEY POINT: 8635018 **WAYPOINT**: 8635017

LATITUDE: 45 20'54.631" **LATITUDE**: 45 20'55.598"

LONGITUDE: 75 53'09.686" **LONGITUDE**: 75 53'04.567"

GMT TIME	BEARING DEGREES	RANGE KM.	NO. SATELLITES/ PDOP
15:14	75.9	.110	5/2
15:20	76.7	.110	5/2
15:23	75.3	.106	5/2
15:25	76.3	.106	5/2
15:28	76.7	.109	5/2
15:30	76.0	.110	5/2
15:32	80.4 *	.216 *	DOWN TO 4 SAT. *
15:34	76.3	.108	5/2
15:36	75.7	.111	5/2
15:38	75.5	.112	5/2
15:40	75.6	.108	5/2

MEAN BEARING: 76.0 , 0.46 2σ

MEAN RANGE: 109 m, 1.90 m 2σ

CALCULATED RANGE: 114.987 m. **CALCULATED BEARING**: 74.955

DELTA RANGE: 109.0 m.(MEASURED) - 114.987 m.(CALCULATED)= 5.987 m.

DELTA BEARING: 76.0 (MEASURED) - 74.955 (CALCULATED) = 1.045 = 18.7 mils

TABLE 4-12 ASHTECH GPS RECEIVER WAYPOINT TEST

DATE: 20/03/1991

SURVEY POINT: 8635018 **WAYPOINT**: 8635017

LATITUDE: 45 20'54.631" **LATITUDE**: 45 20'55.598"

LONGITUDE: 75 53'09.686" **LONGITUDE**: 75 53'04.567"

GMT TIME	BEARING DEGREES	RANGE KM.	NO. SATELLITES/ PDOP
16:41	98.6	.119	3/1
16:44	96.1	.119	3/1
16:47	94.5	.121	3/1
16:49	94.0	.122	3/1
16:51	93.0	.123	3/1
16:53	91.8	.123	3/1
16:55	91.5	.124	3/1
16:57	89.8	.123	3/1
17:00	88.3	.124	3/1

MEAN BEARING: 93.1 , 2.99 2σ

MEAN RANGE: 122 m, 1.83 m 2σ

CALCULATED RANGE: 114.987 m. **CALCULATED BEARING**: 74.955

DELTA RANGE: 122.0 m.(MEASURED) - 114.987 m.(CALCULATED)= 7.013 m.

DELTA BEARING: 93.1 (MEASURED) - 74.955 (CALCULATED) = 18.145 = 324 mils

TABLE 4-13 ASHTECH GPS RECEIVER WAYPOINT TEST

DATE: 20/03/1991

SURVEY POINT: 8635018 **WAYPOINT**: 8635017

LATITUDE: 45 20'54.631" **LATITUDE**: 45 20'55.598"

LONGITUDE: 75 53'09.686" **LONGITUDE**: 75 53'04.567"

GMT TIME	BEARING DEGREES	RANGE M.
14:07	74.8	114.6
14:10	73.6	117.2
14:15	75.7	118.7
14:20	73.4	118.1
14:25	72.8	118.9
14:30	71.7	128.1
14:35	74.6	112.6
14:40	75.3	107.7
14:45	75.3	102.5
14:50	70.9	111.2
14:55	72.0	107.8
15:00	72.9	105.8

MEAN BEARING: 73.6 , 1.51 2σ

MEAN RANGE: 113.6 m, 6.82 m 2σ

CALCULATED RANGE: 114.987 m. **CALCULATED BEARING**: 74.955

DELTA RANGE: 113.6 m.(MEASURED) - 114.987 m.(CALCULATED)= 1.38 m.

DELTA BEARING: 73.6 (MEASURED) - 74.955 (CALCULATED) = 1.36 = 24.3 mils

TABLE 4-14 PLESSEY GPS RECEIVER WAYPOINT TEST

DATE: 20/03/1991

SURVEY POINT: 8635018 **WAYPOINT:** 8635017

LATITUDE: 45 20'54.631" **LATITUDE:** 45 20'55.598"

LONGITUDE: 75 53'09.686" **LONGITUDE:** 75 53'04.567"

GMT TIME	BEARING DEGREES	RANGE M.
14:07	78	144
14:10	84	125
14:15	80	142
14:20	73	150
14:25	80	140
14:30	74	144
14:35	77	142
14:40	82	133
14:45	80	136
14:50	82	139
14:55	79	138
15:00	81	135

MEAN BEARING: 79.17 , 3.10 2σ

MEAN RANGE: 139 m, 6.11 m 2σ

CALCULATED RANGE: 114.987 m. **CALCULATED BEARING:** 74.955

DELTA RANGE: 139.0 m.(MEASURED) - 114.987 m.(CALCULATED)= 24.0 m.

DELTA BEARING: 79.17 (MEASURED) - 74.955 (CALCULATED) = 4.2 = 75.0 mils

TABLE 4-15 TRIMPACK GPS RECEIVER WAYPOINT TEST

DATE: 21/03/1991

REFERENCE SURVEY POINT: 8635001

LATITUDE: 45 21'18.306'

LONGITUDE: 75 53'0.964"

NOTE: Delta bearing is the mean bearing of 7 measurements taken from the reference survey point to a waypoint.

Delta range is the mean range of 7 measurements taken from the reference survey point to a waypoint.

WAYPOINT	DELTA BEARING	DELTA RANGE m
8635003	3.62	3.69
8635004	2.55	9.74
8635005	1.70	14.31
8635006	2.22	18.94
8635007	5.94	19.10
8635009	6.06	13.52

MEAN DELTA BEARING: 3.68 , 1.74 2σ = 65.7 mils, 31.1 mils 2σ

MEAN DELTA RANGE: 13.22 m, 5.35 m 2σ

TABLE 4-16 ASHTECH GPS RECEIVER WAYPOINT TEST SUMMARY

DATE: 21/03/1991

REFERENCE SURVEY POINT: 8635001

LATITUDE: 45 21'18.306'

LONGITUDE: 75 53'0.964"

NOTE: delta bearing is the mean bearing of 3 measurements taken from the reference survey point to a waypoint.

Delta range is the mean range of 3 measurements taken from the reference survey point to a waypoint.

WAYPOINT	DELTA BEARING	DELTA RANGE m
8635003	3.76	1.02
8635004	2.85	6.01
8635005	1.77	13.37
8635006	1.31	21.13
8635007	5.11	22.29
8635009	6.7	17.86

MEAN DELTA BEARING: 3.58 , 1.87 2σ = 63.9 mils, 33.4 mils 2σ

MEAN DELTA RANGE: 13.61 m, 7.81 m 2σ

TABLE 4-17 PLESSEY GPS RECEIVER WAYPOINT TEST SUMMARY

DATE: 21/03/1991

REFERENCE SURVEY POINT: 8635001

LATITUDE: 45 21'18.306'

LONGITUDE: 75 53'0.964"

NOTE: Delta bearing is the mean bearing of 3 measurements taken from the reference survey point to a waypoint.

Delta range is the mean range of 3 measurements taken from the reference survey point to a waypoint.

WAYPOINT	DELTA BEARING	DELTA RANGE m
8635003	1.6	16.69
8635004	2.05	15.41
8635005	2.86	2.86
8635006	6.41	0.13
8635007	9.17	6.94
8635009	4.6	18.24

MEAN DELTA BEARING: 4.45 , 2.66 2σ = 79.5 mils, 47.5 mils 2σ

MEAN DELTA RANGE: 10.05 m, 7.07 m 2σ

TABLE 4-18 TRIMPACK GPS RECEIVER WAYPOINT TEST SUMMARY

DATE: 21/03/1991

SURVEY POINT: 8635001 **WAYPOINT:** 8635003

LATITUDE: 45 21'18.306" **LATITUDE:** 45 21'28.088"

LONGITUDE: 75 53'0.964" **LONGITUDE:** 75 53'06.951"

TIME GMT	BEARING DEG.	RANGE IN M.
14:35	349	290
14:50	349	290
15:00	355	300

MEAN BEARING: 351.0 , 2.83 2σ

MEAN RANGE: 293.33 m, 4.71 m 2σ

CALCULATED RANGE: 328.69 m. **CALCULATED BEARING:** 336.73

DELTA RANGE: 293.33 m.(MEASURED) - 328.69 m.(CALCULATED) = 35.36 m.

DELTA BEARING: 351.0 (MEASURED) - 336.73 (CALCULATED) = 14.27 = 308 mils

TABLE 4-19 MAGELLAN GPS RECEIVER WAYPOINT TEST

DATE: 22/03/1991

SURVEY POINT: 8635017 **WAYPOINT**: 653001

LATITUDE: 45 20'55.598" **LATITUDE**: 45 22'20.505"

LONGITUDE: 75 53'04.567" **LONGITUDE**: 75 44'36.880"

ELEVATION: 74.052 m. **ELEVATION**: 114.066 m.

GMT TIME	BEARING DEGREES	RANGE KM.	NO. SATELLITES/ PDOP
14:06	76.7	11.376	5/3
14:08	76.7	11.372	5/3
14:10	76.7	11.373	5/3
14:12	76.7	11.373	5/3
14:14	76.7	11.374	5/3
14:16	76.7	11.374	5/3
14:18	76.7	11.377	5/3
14:20	76.7	11.376	5/3
14:22	76.7	11.377	5/3
14:24	76.7	11.378	4/4

MEAN BEARING: 76.7 , 0 2σ

MEAN RANGE: 11.375 km, 0.002 km 2σ

CALCULATED RANGE: 11.321 km. **CALCULATED BEARING**: 76.614

DELTA RANGE: 11.375 km.(MEASURED)-11.321 km.(CALCULATED)= 0.054 km.

DELTA BEARING: 76.7 (MEASURED) - 76.614 (CALCULATED) = 0.086 = 1.5 mils

TABLE 4-20 ASHTECH GPS RECEIVER WAYPOINT TEST

DATE: 22/03/1991

SURVEY POINT: 8635017 **WAYPOINT**: 653001

LATITUDE: 45 20'55.598" **LATITUDE**: 45 22'20.505"

LONGITUDE: 75 53'04.567" **LONGITUDE**: 75 44'36.880"

ELEVATION: 74.052 m. **ELEVATION**: 114.066 m.

GMT TIME	BEARING DEGREES	RANGE KM.	NO. SATELLITES/ EPE
14:15	76.5	11.32	5
14:17	76.6	11.30	5
14:20	76.7	11.30	5
14:22	76.9	11.33	4
14:25	76.5	11.34	5
14:28	76.5	11.34	5
14:30	76.8	11.28	5/6 m
14:33	76.8	11.28	5/6 m
14:35	76.8	11.287	5/6 m
14:40	76.7	11.29	5/6 m
14:45	76.7	11.29	5/6 m

MEAN BEARING: 76.68 , 0.13 2σ

MEAN RANGE: 11.30 km, 0.023 km 2σ

CALCULATED RANGE: 11.321 km. **CALCULATED BEARING**: 76.614

DELTA RANGE: 11.30 km.(MEASURED)-11.321 km.(CALCULATED)= 0.021 km.

DELTA BEARING: 76.68 (MEASURED) - 76.614 (CALCULATED) = 0.066 = 1.2 mils

TABLE 4-21 PLESSEY GPS RECEIVER WAYPOINT TEST

DATE: 22/03/1991

SURVEY POINT: 8635017 **WAYPOINT**: 653001

LATITUDE: 45 20'55.598" **LATITUDE**: 45 22'20.505"

LONGITUDE: 75 53'04.567" **LONGITUDE**: 75 44'36.880"

ELEVATION: 74.052 m. **ELEVATION**: 114.066 m.

GMT TIME	BEARING DEGREES	RANGE KM.
14:15	77	11.4
14:17	77	11.4
14:20	77	11.4
14:22	77	11.4
14:25	77	11.4
14:28	77	11.4
14:30	77	11.4
14:33	77	11.4
14:35	77	11.4
14:40	77	11.4
14:45	77	11.4

MEAN BEARING: 77 (5 SATELLITE COVERAGE)

MEAN RANGE: 11.4 km. (5 SATELLITE COVERAGE)

CALCULATED RANGE: 11.321 km. **CALCULATED BEARING**: 76.614

DELTA RANGE: 11.4 km.(MEASURED)-11.321 km.(CALCULATED)= 0.079 km.

DELTA BEARING: 77 (MEASURED) - 76.614 (CALCULATED) = 0.316 = 5.4 mils

TABLE 4-22 TRIMPACK GPS RECEIVER WAYPOINT TEST

4.4 GPS DIFFERENTIAL POINT POSITION AND WAYPOINT TEST RESULTS

On the 19th of March 1991, a differential point position and waypoint test was performed with the Ashtech XII receivers. Measurements were taken with one receiver from a reference position (survey point 8635018), while another recorded data at a waypoint survey point 8635017). Recorded data (14:23 to 17:25 GMT) was post processed. For waypoint 8635017, the delta Latitude and delta Longitude (table 4-23) of the actual waypoint position and the differentially calculated position were 0.0 m and 0.022 m respectively. The differential solution for range and bearing from reference point 8635018 to waypoint 8635017 was calculated. For waypoint 8635017, the delta range and bearing between the calculated and the differential solution were 0.350 m and 0.045°.

On the 22nd of March 1991, a differential point position and waypoint test was performed with the Ashtech XII receiver. Measurements were taken from a reference position (1st order survey point 8635017) to 2 selected waypoints (1st order survey points 8635001 and 8635009). The data collected was post processed. For waypoint 8635001, the delta Latitude and the delta Longitude (table 4-24) of the actual waypoint position and the differentially calculated position were 0.247 m and 0.911 m. For waypoint 8635009, the delta Latitude and delta Longitude (table 4-25) of the actual waypoint position and the differentially calculated position were 0.123 m and 0.694 m. The differential solution for range and bearing from reference point 8635017 to waypoints 8635001 and 8635009 was calculated. For waypoint 8635001, the delta range and delta bearing of the calculated versus the differential solutions were 0.540 m and 0.091°. For waypoint 8635009, the delta range and the delta bearing were 0.302 m and 0.0001°.

DATE: 19/03/1991

SURVEY POINT (REFERENCE): 86350918 **WAYPOINT:** 8635017

LATITUDE: 45 20'54.631" **LATITUDE:** 45 20'55.598"

LONGITUDE: 75 53'09.686" **LONGITUDE:** 75 53'04.567"

ELEVATION: 73.721 m **ELEVATION:** 74.052 m

Ashtech differentially post processed point solution for

Waypoint 8635017: Latitude: 45 20'55.5979"
Longitude: 75 53'04.5682"

Delta Latitude: 45 20'55.598" (differential solution)
45 20'55.598" (8635017)
.000"

Delta Latitude: 0.000" x 30.867 m/sec = 0.0 m

Delta Longitude: 75 53'04.568" (differential solution)
75 53'04.567" (8635001)
.001"

Delta Longitude: 0.001 sec x 21.693 m/sec = 0.0217 m

Calculated range and bearing from reference point 8635018 and waypoint 8635017 are: Range: 114.987 m
Bearing: 74.955

Delta Range: 115.337 m (differential solution)
114.987 m (calculated)
0.350 m

Delta Bearing: 75.000 (differential solution)
74.955 (calculated)
0.045 (0.8 mils)

TABLE 4-23 ASHTECH GPS DIFFERENTIAL POINT POSITION AND WAYPOINT TEST

DATE: 22/03/1991

SURVEY POINT (REFERENCE): 86350917 **WAYPOINT:** 8635001

LATITUDE: 45 20'55.598" **LATITUDE:** 45 21'18.306"

LONGITUDE: 75 53'04.567" **LONGITUDE:** 75 53'00.964"

ELEVATION: 74.052 m **ELEVATION:** 64.748 m

Ashtech differentially post processed point solution for

waypoint 8635001: Latitude: 45 21'18.3137"
Longitude: 75 53'00.9221"

Delta Latitude: 45 21'18.314" (differential solution)
45 21'18.306" (8635001)
.008"

Delta Latitude: 0.008" x 30.867 m/sec = 0.247 m

Delta Longitude: 75 53'00.922" (differential solution)
75 53'00.964" (8635001)
.042"

Delta Longitude: 0.042 sec x 21.693 m/sec = 0.911 m

Calculated range and bearing from reference point 8635017 and waypoint 8635001 are: Range: 705.272 m
Bearing: 6.363

Delta Range: 705.812 m (differential solution)
705.272 m (calculated)
0.540 m

Delta Bearing: 6.454 (differential solution)
6.363 (calculated)
0.091 (1.6 mils)

TABLE 4-24 ASHTECH GPS DIFFERENTIAL POINT POSITION AND WAYPOINT TEST

DATE: 22/03/1991

SURVEY POINT (REFERENCE): 86350917 **WAYPOINT:** 8635009

LATITUDE: 45 20'55.598" **LATITUDE:** 45 21'17.951"

LONGITUDE: 75 53'04.567" **LONGITUDE:** 75 52'54.109"

ELEVATION: 74.052 m **ELEVATION:** 64.830 m

Ashtech differentially post processed point solution for

waypoint 8635009: Latitude: 45 21'17.9548"
Longitude: 75 52'54.1406"

Delta Latitude: 45 21'17.955" (differential solution)
45 21'17.951" (8635001)
.004"

Delta Latitude: 0.004" x 30.867 m/sec = 0.123 m

Delta Longitude: 75 52'54.141" (differential solution)
75 52'54.109" (8635001)
.032"

Delta Longitude: 0.032 sec x 21.693 m/sec = 0.694 m

Calculated range and bearing from reference point 8635017 and waypoint 8635001 are: Range: 726.310 m
Bearing: 18.2011

Delta Range: 726.612 m (differential solution)
726.310 m (calculated)
0.302 m

Delta Bearing: 18.2012 (differential solution)
18.2011 (calculated)
0.0001 (0 mils)

TABLE 4-25 ASHTECH GPS DIFFERENTIAL POINT POSITION AND WAYPOINT TEST

4.5 KINEMATIC RESULTS

Kinematic test results were, unfortunately, inconclusive. The data was sent back to the manufacturer for analysis but no results could be obtained. The cause of this is unknown but may be due to lack of experience with both the kinematic survey procedures and the use of the post-processing software.

4.6 GENERAL RECEIVER CHARACTERISTICS

4.6.1 Ashtech XII

The start-up and operation of the Ashtech receiver was very simple. The only problem encountered during the tests was the entry of alphanumeric characters on the keyboard. An 'up' key had to be pushed until the required letter appeared on the display, then one had to determine which numeric key it was replacing. With more practice this operation would become easier.

From cold start:
- average time to acquire 1st satellite: 40 seconds
- average time to first fix: 1.5 minutes

Note: The Ashtech automatically acquires an almanac. When the receiver is initialized in the same area as the previous shut-down, the receiver acquired a satellite within seconds of turn-on.

4.6.2 Plessey PA9052

The receiver tested was an engineering model, controlled via Plessey software on a Toshiba Laptop computer. The start-up and operation involved time-consuming multiple steps. On some occasions the receiver would not initialize, power had to be turned off, then on and the receiver re-initialized. The operation of a full production model complete with a CDU (control display unit) would be simpler.

From cold start:
- average time to acquire 1st satellite: 90 seconds
- average time to collect an almanac: automatic
- average time to first fix: 8.5 minutes

4.6.3 Trimble TRIMPACK

The TRIMPACK receiver is a very simple, user friendly receiver. Data display and entry are controlled by a rotary switch and a sequencing toggle switch, respectively.

Initial acquisition is automatic.

From cold start:
- average time to acquire 1st satellite: 40 seconds
- average time to first fix: 1.5 minutes

4.6.4 Magellan NAV1000M

The Magellan receiver employs a hand-held keyboard for display control and data input. Practice is required to perform data entry through the alpha-numeric keyboard. Almanac collection is user-initiated.

From cold start:
- average time to acquire 1st satellite: 60 seconds
- average time to first fix: 2.5 minutes
- average time to collect almanac: 7 minutes

4.6.5 Ashtech GPS Post Processing Software

Data collected simultaneously by two or more Ashtech receivers in one of four surveying modes (Static, Pseudo kinematic, Kinematic and Antenna swap) can be post-processed with the Ashtech GPS Post Processing Software to obtain precise position and baseline.

The operation of the GPS post processing menu-driven software is difficult (this user did not make use of the tutorial provided). Reading the operations manual supplied enables one to perform the basic processing of collected data. It is recommended that the purchaser take the EDO-sponsored GPS Post Processing software course in order to make full use of the software.

5.0 EVALUATION

5.1 CONCLUSIONS

A review of the test results points out several noteworthy conclusions.

Static point-positioning tests (summarized in Table 4-11) indicate that, with minor exceptions, all receivers meet GPS positioning specifications but do not always satisfy artillery positioning requirements. Discrepancies are most likely due to satellite geometry (PDOP). The Plessey P-Code receiver is the only receiver which would reliably meet the static positioning requirements.

It should be noted that the Plessey GPS antenna was of the order of 5 meters from the desired reference point during the tests since it was mounted on top of the test bed which could not be positioned any closer for fear of 'shielding' the ground-mounted (Trimpack, Magellan and Ashtech) antennas. Nonetheless, the error is within the standard deviation calculated for the Plessey receiver position. No correction for this antenna offset was made during these trials.

Note also that these tests were performed without Selective Availability being implemented. Under SA conditions, static positioning accuracy for the C/A code receivers could be expected to degrade to approximately 100 meters; insufficient to meet the artillery positioning specification.

In waypoint range and bearing determination, again, all receivers functioned normally giving short range accuracies of the order of 10 to 15 metres and bearings within 3 to 5 degrees. At longer ranges (≈11 km), bearing accuracy improves to better than 0.1 degrees for the Ashtech and Plessey receivers, slightly poorer for the Trimpack.

In conclusion, single-receiver waypointing does not appear to meet the artillery positioning and pointing specification, even with the P-Code (Plessey) receiver although, again, perhaps a longer observation time and better PDOP could improve this.

Using the Ashtech receivers in differential mode gives a further improvement in both positioning and bearing to a waypoint. Results indicate range accuracies of less than 1 meter and bearing of <0.1 degrees even for very short ranges (<1 km). Longer observation times (less than 10 minutes were used during these tests), more satellites (the Ashtech

receiver can track up to 12 satellites) and better PDOP would probably permit achievement of desired specifications in most cases.

With respect to kinematic survey results, as explained previously, phase tracking difficulties precluded any useful results. In general, the technique requires great care and might not lend itself easily to a military (hostile) environment in its present format.

In summary, the artillery positioning and pointing specifications could not be met without differential GPS which would imply, of course, that a forward observer would have to carry a receiver with him and relay the GPS information back to the artillery position. The desired accuracies could probably be achieved under good satellite coverage and sufficient observation time. Such a system appears to be feasible.

5.2 RECOMMENDATIONS

The use of differential GPS shows potential for achieving the artillery survey positioning and pointing requirements as contained in STANAG 2373 but several points are worth considering.

A GPS-based system, as tested, could provide position and bearing information but artillery barrel attitude (elevation) must be separately derived. Existing systems to perform this function include inertial-based systems such as the Position and Azimuth Determining System (PADS), a full inertial navigation system. This system can achieve the desired accuracies but usually requires external aiding such as a GPS receiver. PADS is also extremely expensive (> $200K).

A new concept may provide a more cost-effective way to achieve the desired specifications. In recent years, much attention has been focused on deriving attitude information from GPS by the use of several antennas and the measurement of the relative phase difference between them. One system in particular shows promise. This is the Ashtech 3DF system which employs a single 24-channel receiver tied to 3 or 4 antennas mounted on the body of interest (vehicle, artillery piece, etc.). Attitude accuracies of 1 milliradian are specified and better results have been achieved in early tests. Such a system, coupled to a second GPS receiver for differential positioning accuracy, could be a promising solution to the artillery positioning and pointing problem.

Further investigation in this area is recommended.

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Four GPS receivers including the Plessey PA9052, Ashtech XII, Trimble TRIMPACK and Magellan NAV1000M were evaluated for performance and suitability for the positioning and pointing of artillery.

Specifications for accuracy in positioning and pointing, as defined by STANAG 2373, are 17.5 metres (CEP) and 0.60 mils, respectively.

The receivers were evaluated for static positioning, short and mid-range (≈11km) waypointing (bearing determination), differential positioning and waypointing, kinematic positioning and general receiver characteristics.

The evaluations were carried out in March of 1991 and while Selective Availability (SA) was not implemented.

Static positioning (without SA) met artillery specification. Bearing determination to a given waypoint, both short and mid-range, was 3 to 5 degrees but improved under differential GPS processing to better than 0.1 degree. Kinematic survey yielded indeterminate results.

The use of differential GPS under good satellite geometry conditions and with adequate observation times may be a feasible solution for the artillery survey positioning and pointing requirement.

Other techniques employing GPS which show potential for this application are also discussed.

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